Glider-based Observations of Kuroshio Seasonal Variability and Loop-Current Intrusion into the South China Sea

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LONG-TERM GOALS

Two long-term goals, one technical and one scientific motivate this project. The technical goal is to advance techniques of observing the upper ocean, in this case proving the utility of underwater gliders. The scientific goal is to understand the effects of mesoscale processes on larger scales such as the general circulation, and on smaller scales such as internal waves.

OBJECTIVES

The primary technical objective is to demonstrate the use of a glider fleet in sampling a strong boundary current where the flow is often stronger than the glider can overcome.

The general scientific objective is to quantify the spatial structure and temporal evolution of the southern reaches of the Kuroshio. We plan to characterize the annual cycle of the Kuroshio and its associated mesoscale field. A next objective is to observe and quantify intrusions of the Kuroshio through the Luzon Strait. These mesoscale observations then provide the background on which strong nonlinear internal waves propagate.

APPROACH

A novel application of maturing autonomous glider technologies will allow repeated occupation of multiple sections along approximately 1000 km of the Kuroshio's pathway (from Luzon to Ryukyu Islands). Gliders cycle from the surface to 1000 m at roughly six-hour intervals traveling 6 km through the water, traversing approximately 2000-3000 km over the course of a 3-4 month deployment. Observed variables include pressure, temperature, salinity, depth-averaged velocity, dissolved oxygen, and optical properties. Gliders steer through the water by controlling attitude (pitch and roll) and can thus navigate between waypoints to execute survey patterns; or they hold station while profiling and collect Eulerian time series as a 'virtual mooring'. Gliders are commanded remotely and report their measurements via Iridium satellite telephone at the conclusion of each dive. The vehicles also archive all data to onboard storage for delayed mode transmission or post-recovery interrogation. They use GPS navigation at the sea surface to dead reckon toward commanded targets. Navigation and knowledge of vehicle buoyancy and pitch angle allows estimation of depth-averaged current and

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14. ABSTRACT
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suitably energetic vertical velocity fluctuations. Gliders have been deployed and recovered from a wide range of platforms including small rubber boats, chartered fishing vessels and large research ships.

Craig Lee of University of Washington is an equal partner in this collaborative project. All operations will be joint efforts, with the expectation that collaboration will produce efficiencies. David Tang of Taiwan has aided with local logistics, including providing a vessel for glider recovery.

WORK COMPLETED

Field operations in the Kuroshio were completed successfully during the past year. Thirteen gliders (7 Sprays from SIO and 6 Seagliders from UW) were deployed and recovered starting in April 2007 and ending in June 2008. Turnarounds were done in July 2007, October 2007, and March 2008. Over 5000 dives to as deep as 1000 m were done as the gliders covered over 20,000 km in more than 1000 glider-days.

Most of the gliders followed a zig-zag path northward, often in formation separated along the path by 3-7 days. The separation in space and time allows multiple occupations of sections to observe the evolution of mesoscale features. Such statistics as the autocovariance and structure function have been calculated. Three gliders crossed the Kuroshio through the Luzon Strait. One of these gliders made two two-week-long time-series stations in the path of tidal internal waves generated at the Strait.

We attended a planning meeting November 2006 in Taiwan to consult with international colleagues. Preliminary results were presented a meeting September 2007 in Alaska. Presentations were made at the 2008 Ocean Sciences Meeting in Florida. Two presentations are planned at the 2008 Fall AGU Meeting.

RESULTS

The technical objective of demonstrating the utility of a glider fleet in a region of strong currents has been achieved. Depth-average currents greater than 0.25 m/s (glider speed through the water) occurred 5-30% of the time depending on the deployment. In the presence of these strong flows, we were able to hit desired waypoints (Figure 1). Furthermore, we were able to cross the Kuroshio through the Luzon Strait with three separate gliders.

Preliminary scientifc results emphasize the mesoscale variability, which is often so strong that it obscures the northward flowing Kuroshio. A salinity maximum is observed at 100-200 m, strongest in the region of the Kuroshio (Figure 2). Low salinity intermediate water near 500 m depth is found to have structure on roughly 50 km horizontal scales. Consecutive sections, occupied weeks apart, show the evolution of salinity anomalies in this intermediate layer. The Kuroshio, and associated mesoscale, is observed to strengthen as it flows northward. Strong stirring is evident in the salinity extrema. This feature is consistent with the relatively young age of the water in the extrema relative to the inflection level between.

Two time-series stations showed the steepening of large-amplitude (over 100 m) internal waves as they propagated westward (Figure 3). The glider proved to be a surprisingly good platform for observing these nonlinear internal waves. In this application, the glider profiled from the surface to 500 m every 3 hours. Vertical velocities of over 0.1 m/s were observed as the glider’s ascent was occassionally

reversed during strong downwelling events. When the nonlinear internal waves were observed, they were found at a consistent daily interval, consistent with moored results from the area.

IMPACT/APPLICATIONS

The demonstration of glider utility in a strong western boundary current should influence future glider operations in similarly strong flows.

The use of gliders to hold station and observe internal waves may prove to have some advantages, as the gliders can be positioned interactively to be in path of the waves.

RELATED PROJECTS

This project takes advantage of glider technology that has been developed through grants from several agencies including ONR, NSF, and NOAA.

PUBLICATIONS

Van Uffelen, L. J., P. F. Worcester, M. A. Dzieciuch, and D. L. Rudnick, 2008: The vertical structure of shadow-zone arrivals at long range in the ocean. *J. Acoust. Soc. Am.*, submitted.

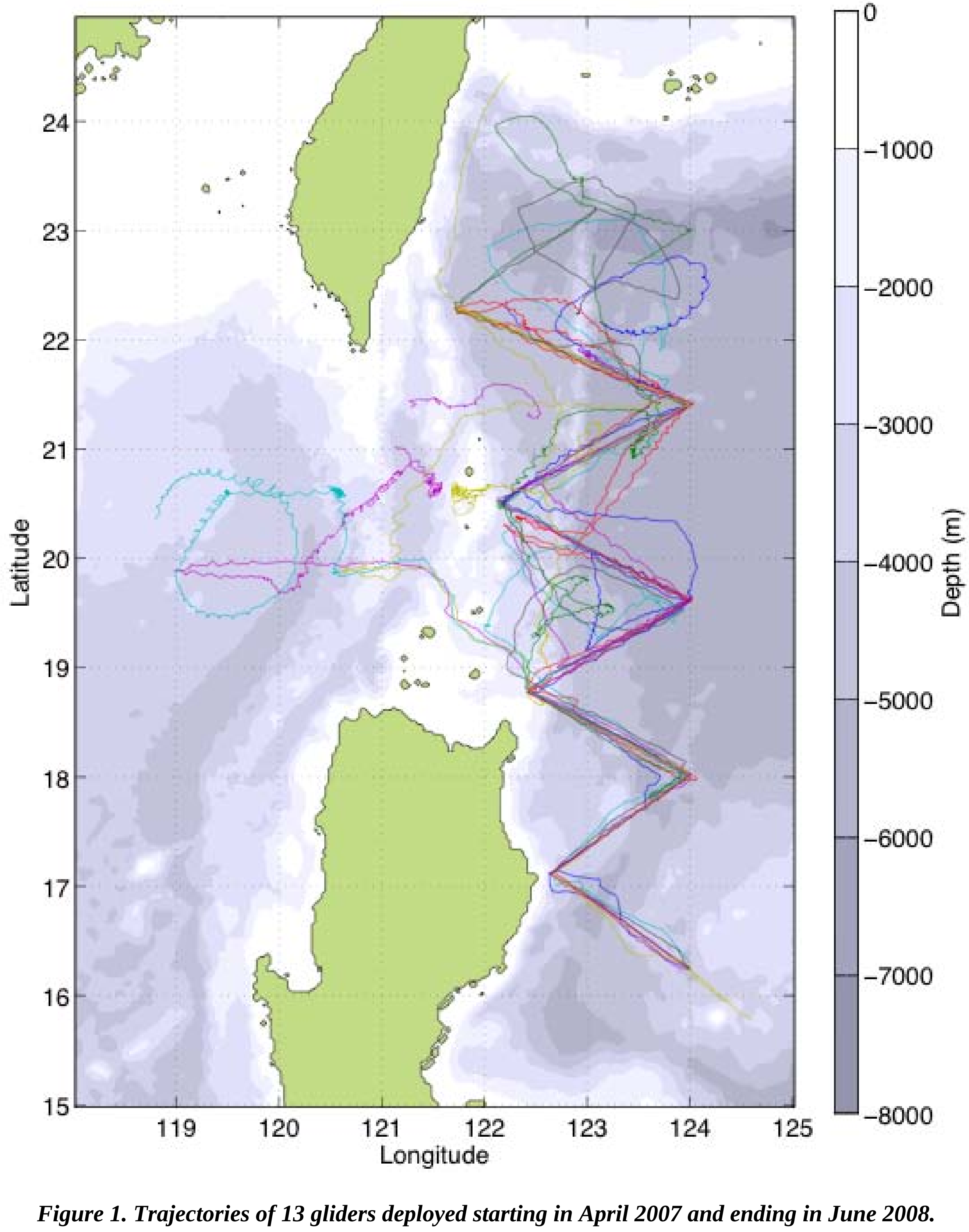

Figure 1. Trajectories of 13 gliders deployed starting in April 2007 and ending in June 2008. Gliders were deployed in the south and proceeded in a zig-zag pattern heading north. Three gliders crossed the Kuroshio through the Luzon Strait.

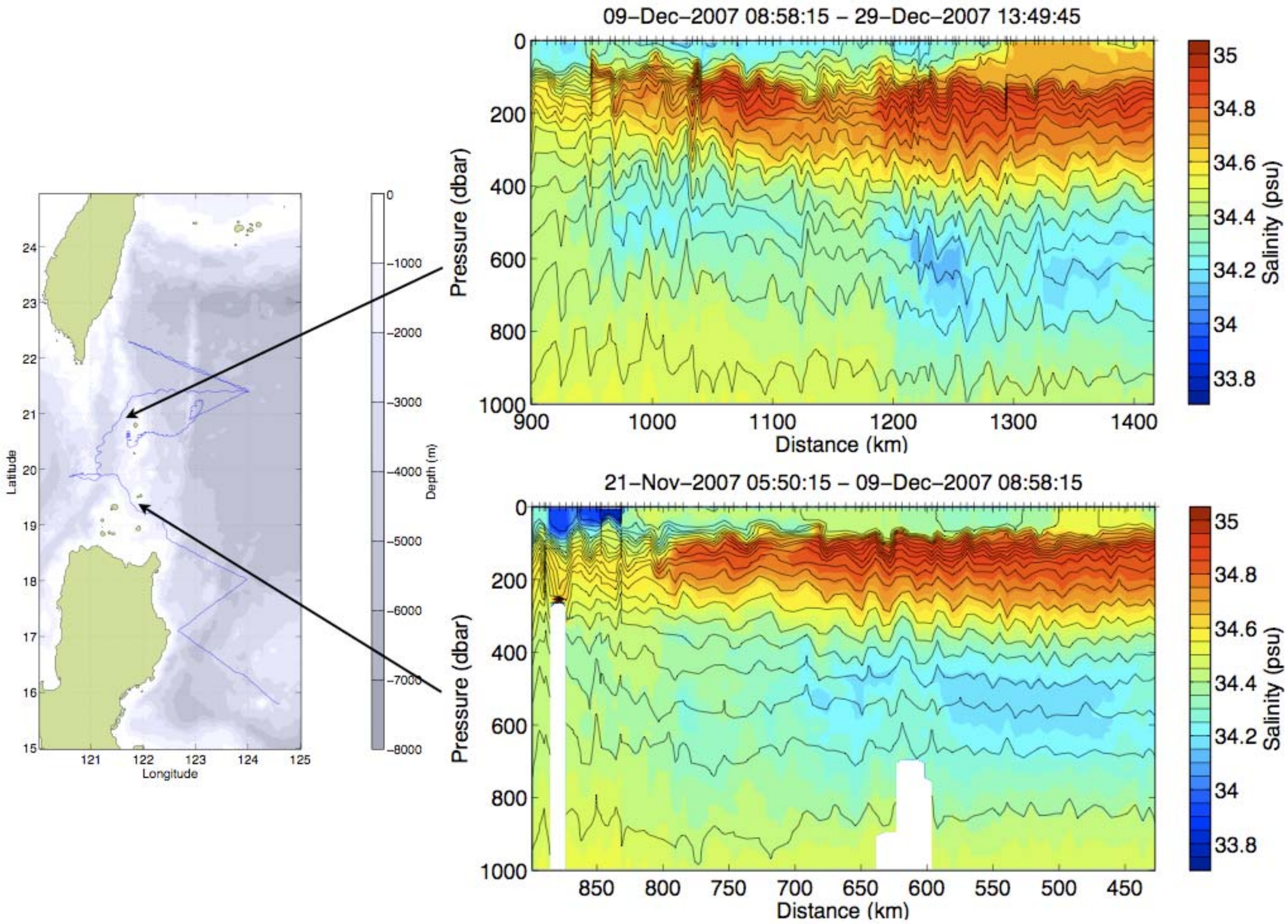

Figure 2. Salinity (shading) and potential density (contours, 0.25 kg/m^3 interval) sections crossing the Kuroshio through the Luzon Strait. Note the extrema in salinity near 200 and 500 dbar. The shallow salinity maximum includes water of southern origin The salinity minimum near 500 dbar is reminiscent of North Pacific Intermediate Water. The patchy structure in this minimum is indicative of mesoscale stirring.

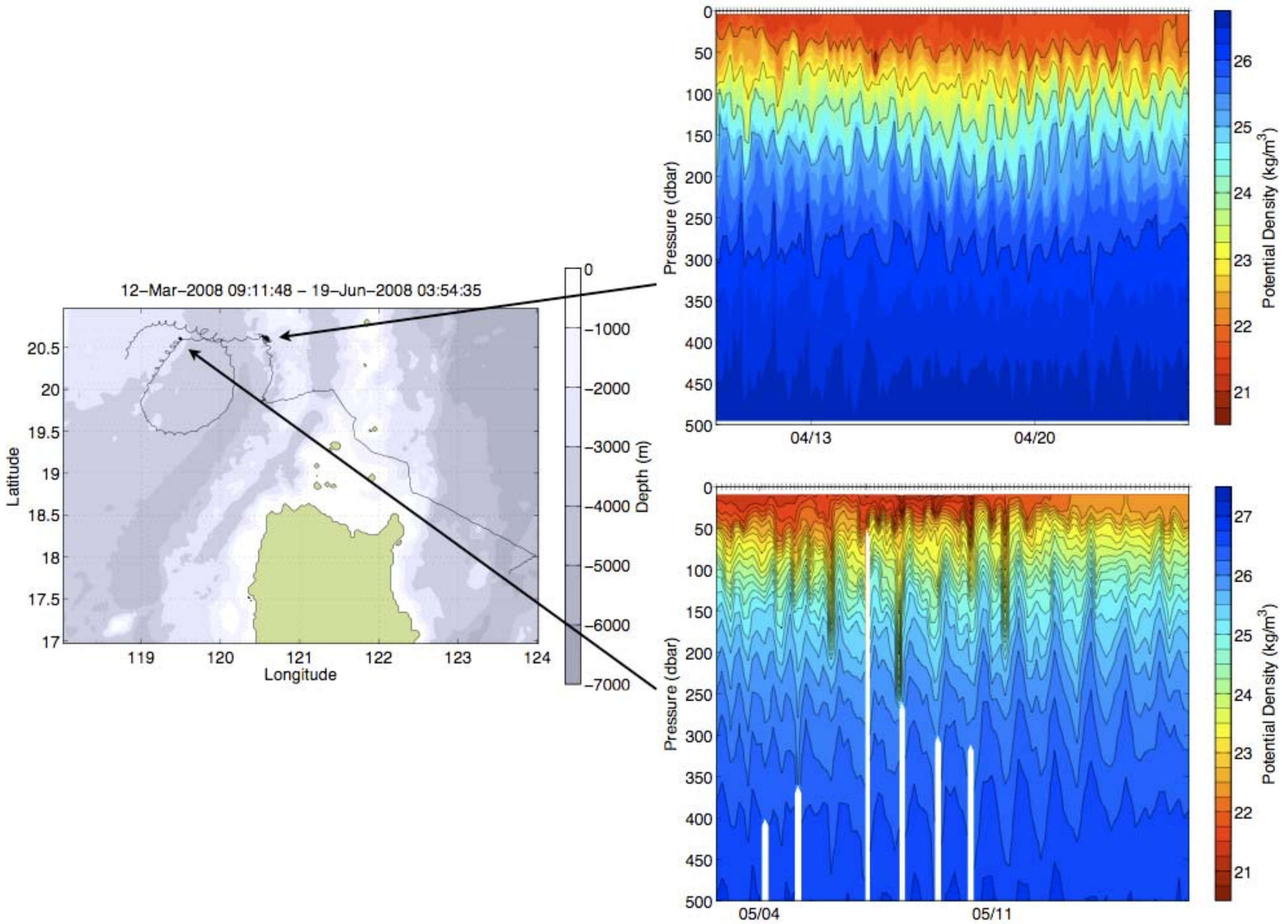

Figure 3. Potential density time-series from stations at 20.6°N, 120.6°E and 20.6°N, 119.5°E. Each station was occupied for about two weeks to observe a complete spring-neap tidal cycle. Note the abrupt over 50 m displacements near 300 m early in the first, eastern time series. The peaks occur on a daily interval. Shallower, the dominant frequency is semidiurnal. Displacements greater than 100 m are prevalent in the second, western time series. Vertical flows were so strong once per day during spring tide that the glider could not descend, resulting in the white gaps in the contoured time series.